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SEISMIC RISK FOR RUSH VALLEY, UTAH AND AN EARTHQUAKE DESIGN ANA--ETC(U)
FEB 78 J R KOLMER

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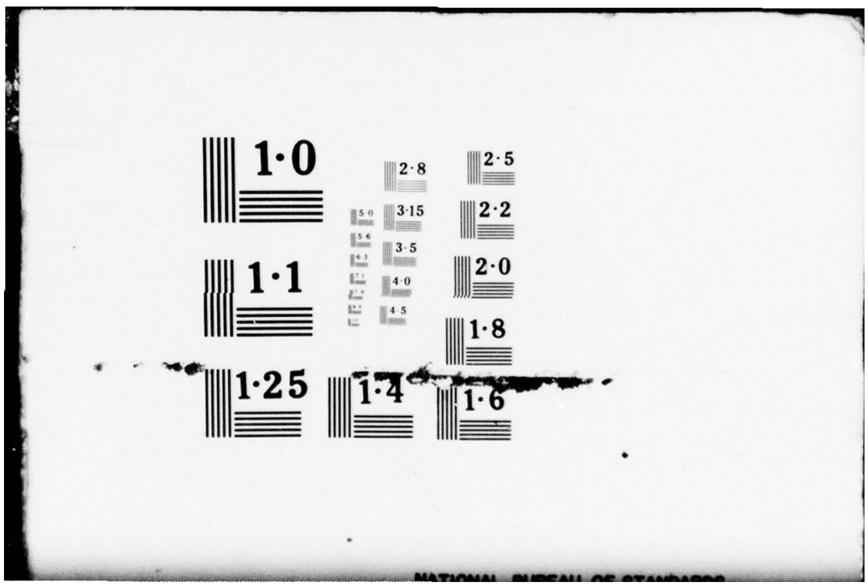
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report contains
Analysis covering the methods used to estimate the average reoccurrence intervals for seismic events, analysis of ammunition storage structures in the Tooele Army Depot South Area, and the testing done on these storage structures as well as the Weteye bombs themselves.

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SEISMIC RISK FOR RUSH VALLEY, UTAH

AND

AN EARTHQUAKE DESIGN ANALYSIS OF AMMUNITION STORAGE FACILITIES

FOR

THE SOUTH AREA OF TOOELE ARMY DEPOT

(9) Final rept.,

Prepared by:

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TECHNICAL SUPPORT OFFICE

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The principal coordinator for the presentation of these data to the State of Utah was Mr. T. Dashiell, Department of Defense Research and Engineering.

SEISMIC RISK FOR RUSH VALLEY, UTAH
AND
AN EARTHQUAKE DESIGN ANALYSIS OF AMMUNITION STORAGE FACILITIES
FOR
THE SOUTH AREA OF TOOELE ARMY DEPOT

Prepared by:

JOSEPH R. KOLMER, CPT

1. Introduction.

a. The science of earthquake analysis is not absoulte. That is to say, the prediction of what earthquake event will occur in a given area, in a given time, is not possible. There are techniques available, however, by which the risk associated with earthquake hazards can be assessed. By using these methods, the average reoccurrence interval for various intensity earthquakes can be estimated. These estimates are an indication of earthquake risk. Just as the risk involved with the reoccurence of a one in ten year flood is higher than the risk involved with the reoccurrence of a one in one hundred year flood, the risk involved with the reoccurrence of one in one hundred year earthquake is higher than the risk involved with the reoccurrence of the one in one thousand year earthquake. It is important that this risk be assessed and the average reoccurrence interval be evaluated in conjunction with the maximum intensity designation for that interval. Through this type of analysis the risks can be evaluated and a determination can be made as to the acceptability of that risk.

b. In a risk analysis of this type it is best if the study can be approached as conservatively as possible. Therefore, this analysis will consider the "worst case" or maximum credible earthquake event that could occur in Rush Valley. The characteristics of the ammunition storage structures as well as the munitions of concern, the Weteye Bomb, will be evaluated against these worse case conditions. It is considered that if these structures and materials can withstand the maximum credible earthquake event, no matter how infrequenty it might occur, the structures and munitions can withstand lesser events.

c. The following analysis will cover the methods used to estimate the average reoccurrence intervals for seismic events, the analysis of ammunition storage structures in the Tooele Army Depot South Area, and the testing done on these storage structures as well as the Weteye bombs themselves. This

discussion will show that:

(1) The reoccurrence interval for large seismic events in Rush Valley is very low.

(2) Based on analysis and testing of ammunition storage structures the failure of these structures due to ground motion caused by earthquakes is not considered a credible possibility.

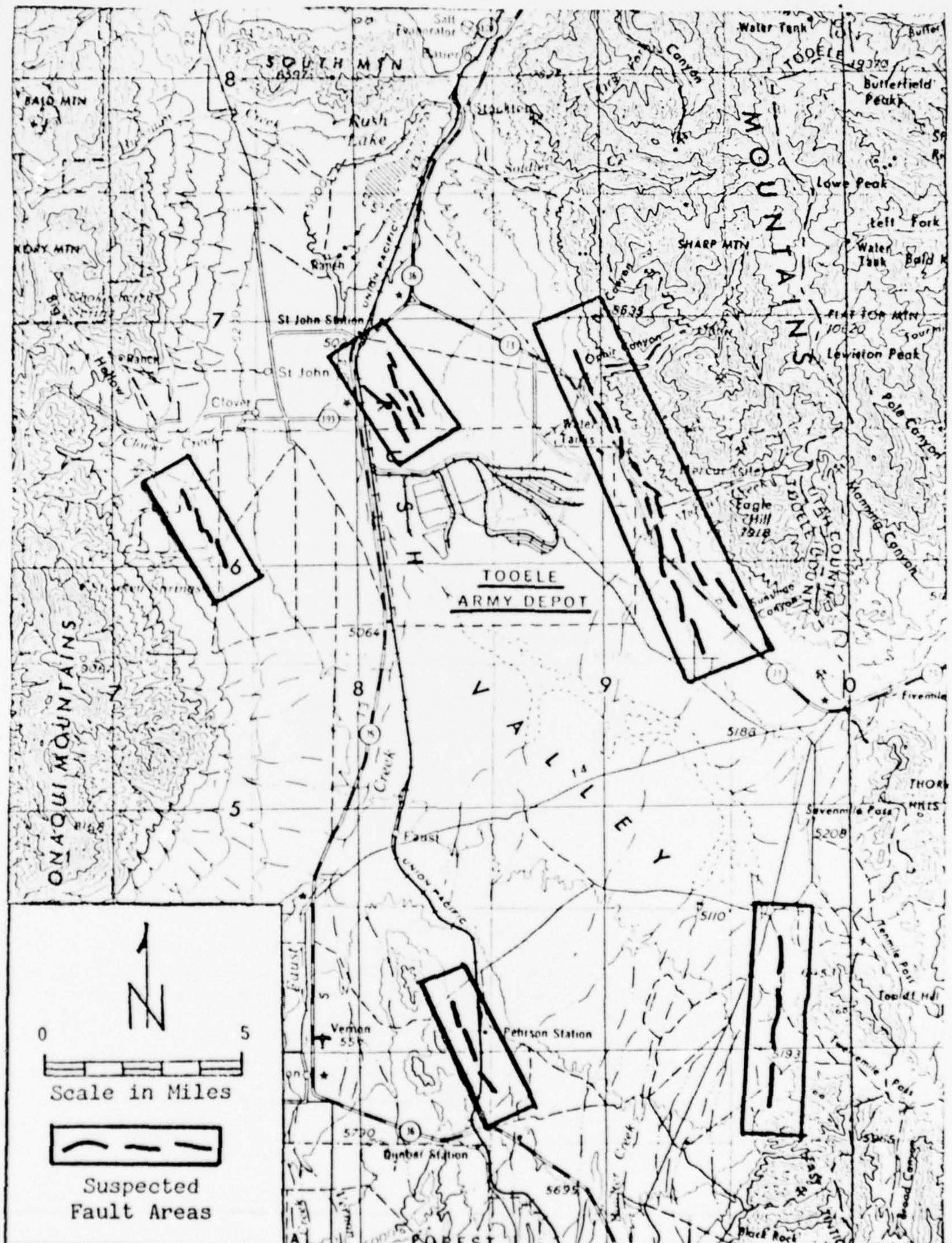
(3) If a faultline should extend through a storage structure due to a large seismic event the structure may be damaged but the handling and drop test for the Weteye bombs show that they can withstand even these severe stress conditions.

2. Discussion and Analysis of Earthquake Risk.

a. For a risk analysis of earthquake hazards there are two prime sources of information. These sources are: (1) the seismic history of the area of concern and, (2) the geologic history and conditions in the area of concern. In the following discussion both of these sources will be addressed and utilized to make an assessment of earthquake risk for the Rush Valley area.

(1) The geological information sources include Dr. Robert Bucknam's open file report[1] (77-495) showing suspected fault scarps on the Tooele 2° map sheet (Figure 1). Dr. Bucknam's map shows that there are five systems of suspected fault scarps in the Rush Valley area. Two of these systems are on the south side of the valley, well removed from the depot area. The three suspected systems in the north part of the valley are closer to the depot area. One system trends along the base of the Oquirrh Mountains on the east side of the valley, the second system is along the base of the Onaqui Mountains on the west side of the valley, and the third system, the system of primary concern, occurs just north of the depot area and trends toward the depot area. This system is of primary concern because it is assumed that if faulting should reoccur due to earthquake activity it will reoccur along existing fault lines. A fault line might extend itself from this system through the depot and through a storage area within the depot.

(2) A general geologic review of fault scarps shows that the average offsets on faults due to a 7.5 Richter magnitude seismic event can be up to five meters. [2,3] Data also indicates that an earthquake with magnitude 7.5 is considered to be the reasonable maximum credible earthquake that might occur in the state of Utah. The length of a scarp produced by such a seismic event is postualted to be approximately 100 kilometers.[4]

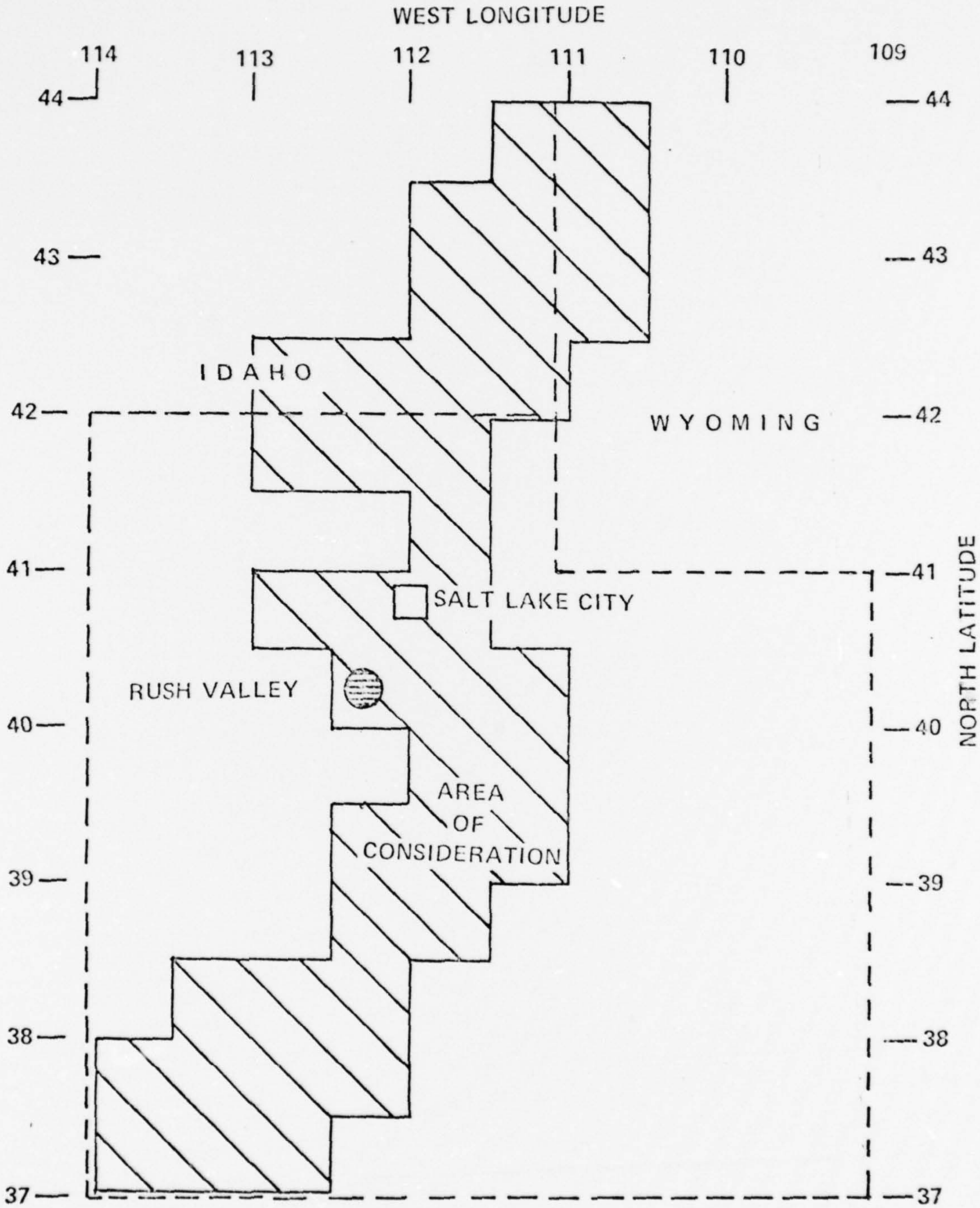


Suspected Fault Areas in Rush Valley, Utah - Reproduced from U.S. Geological Survey Open File Report 77-495 (Bucknam, 1977).

FIGURE 1

b. From the seismic history the largest recorded earthquake in Rush Valley was 4.3 Richter magnitude in 1958.[5] Rush Valley, however, is too small an area and the seismic history is too short to consider an analysis based on the valley itself. The length of the available earthquake record cannot be changed, but the area of consideration can be enlarged for the purposes of analysis. Therefore, a larger area encompassing the earthquake data along the Wasatch front in Utah was considered.[6] Rush Valley is on the fringe but still within the overall area of the Wasatch front earthquake activity. The total area of consideration for this first statistical analysis is shown at Figure 2. The earthquake record for this total area was studied and the number of earthquakes of each intensity for ten year periods was recorded. The listing of how many seismic events per ten year period occurred within this area is shown at Table 1. The listing at Table 1 was reviewed and the completeness of the earthquake record was estimated. The dashed line shown in this table defines the period for which the record is judged to be complete. Based on this estimate of record completeness, the rates of reoccurrence for earthquakes for each maximum intensity V through VIII was determined. These rates are listed in decimal form at the bottom of the table.

c. A graphical presentation of the Table 1 data is shown at Figure 3. In order to make this graph more easily readable, the reciprocal of the rate is determined and graphed against each maximum intensity. This new graph is shown in the lower portion of Figure 4. By using this graph the average reoccurrence interval for each maximum intensity earthquake in the total 35,000 square mile area of consideration can be determined. For example, the average reoccurrence interval for earthquake having maximum intensity V is approximately every two years. The reoccurrence of seismic events in the 390 square mile area of Rush Valley can be scaled from the larger area by using an area ratio. The resultant graph obtained by applying this ratio is shown in the top portion of Figure 4. The conservativeness of this approach should be apparent here. The same acuteness of faulting and earthquakes that occur along the Wasatch front have been scaled into Rush Valley. If the seismic record is reviewed in detail it can be seen that seismic activity along the Wasatch front is historically much greater than within the Rush Valley area, and review of geologic information will show that the faulting along the Wasatch front is more severe than the faults described within the Rush Valley area. Also, the recorded seismic history of Rush Valley shows no large seismic events. This method of analysis will consider the possible occurrence of large events for the valley itself.



MAP OF AREA OF CONSIDERATION FOR SEISMIC EVENT STUDY NO. 1

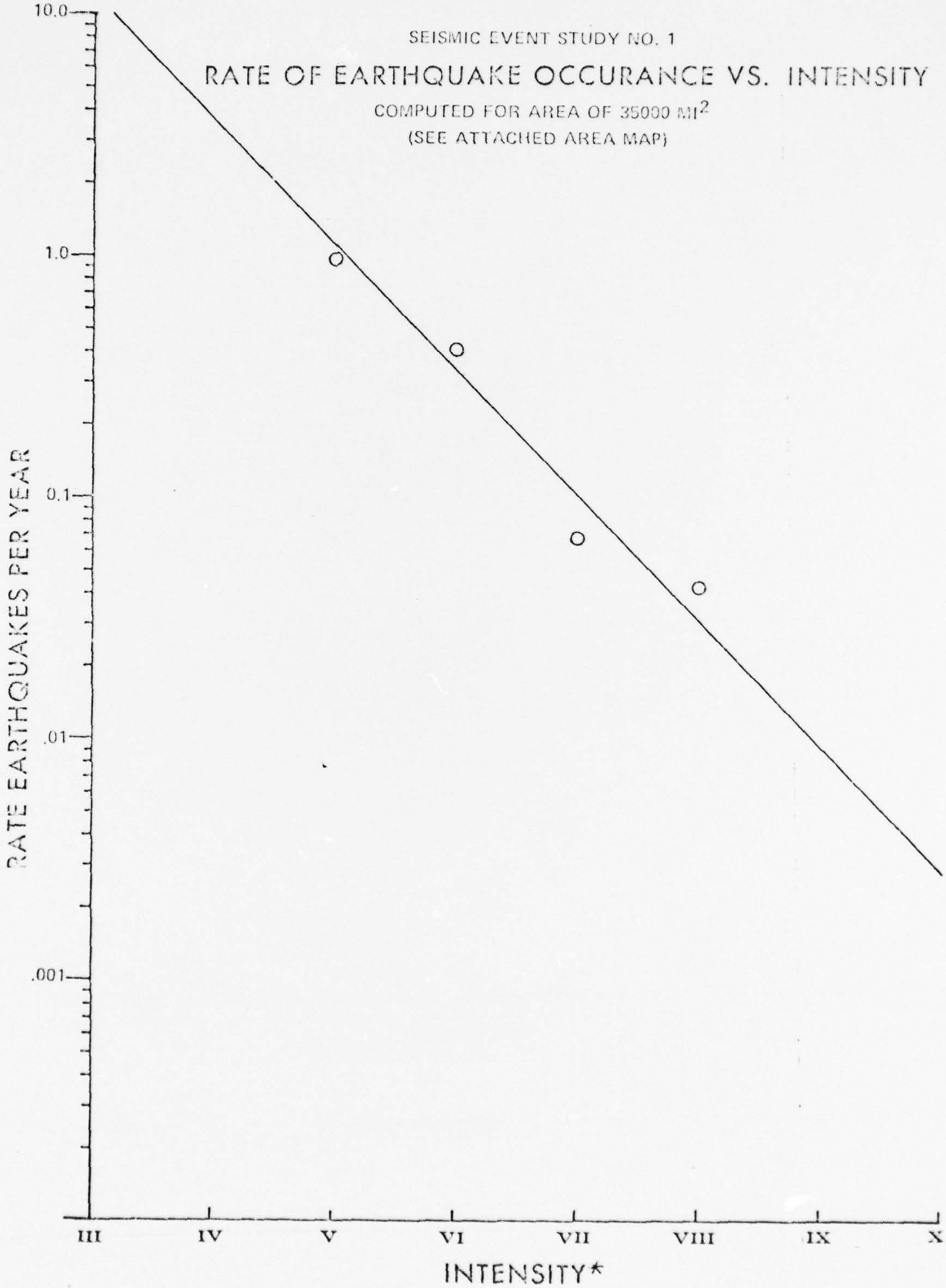
FIGURE 2

TABLE 1

NUMBER OF EVENTS BY INTENSITY PER 10 YEARS

SEISMIC EVENT STUDY #1

Year Group \ Intensity	IV	V	VI	VII	VIII
1853-60		1			
1861-70					
1871-80		3	1		
1881-90			1	1	1
1891-1900			2	2	
1901-10		5	10	2	2
1911-20		9	6		
1921-30		4	1	2	1
1931-40		4	2		1
1941-50	1	6	6		
1951-60		12	4		
1961-70	18	28	5	1	
Events/Yrs		68/70	37/90	8/117	5/117
Decimal Equivalent		0.97	0.41	0.068	0.043



*Modified Mercalli Scale - See Inclosure 3 for definitions.

FIGURE 3

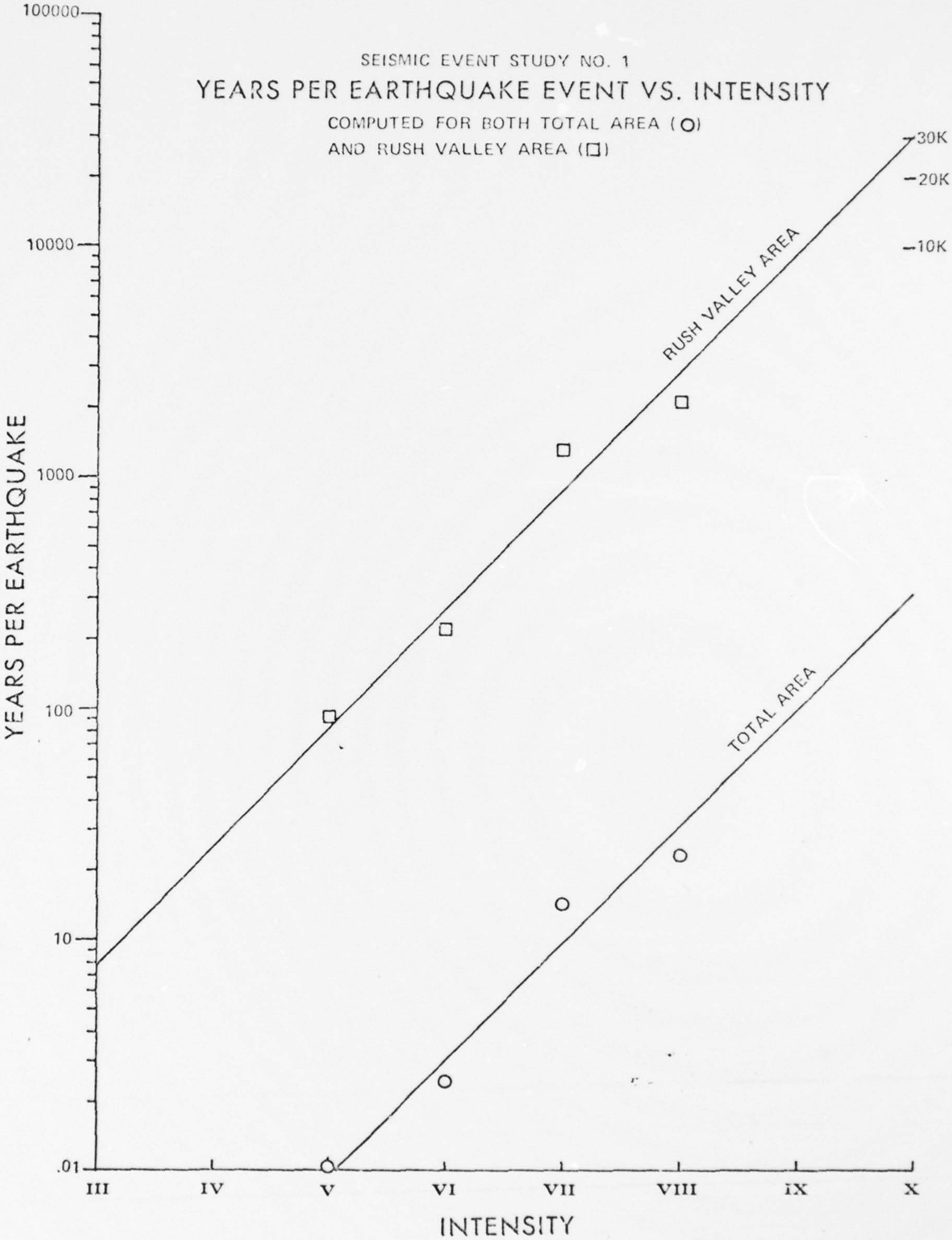

SEISMIC EVENT STUDY NO. 1
YEARS PER EARTHQUAKE EVENT VS. INTENSITY
COMPUTED FOR BOTH TOTAL AREA (O)
AND RUSH VALLEY AREA (□)
YEARS PER EARTHQUAKE
100000
10000
1000
100
10
.01
30K
20K
10K
RUSH VALLEY AREA
TOTAL AREA
III
IV
V
VI
VII
VIII
IX
X
INTENSITY

FIGURE 4

d. As a check on this method of analysis, and in order to insure complete evaluation of all available data, a second seismic record [5] covering the north central portion of the Wasatch front in Utah was consulted and the same type of analyses was performed on these data. The results of this second analysis are presented in Figures 5 thru 7 and Table 2. The comparison of the two analyses reveals good coorelation of results. For example, the average reoccurrence interval for intensity V earthquake by the first study is once in every 85 years, in the second study once in every 80 years. Based on these two analyses it can be seen that the average reoccurrence interval for the maximum credible event in Utah, an intensity X earthquake, is once in every 12,000 to 30,000 years.

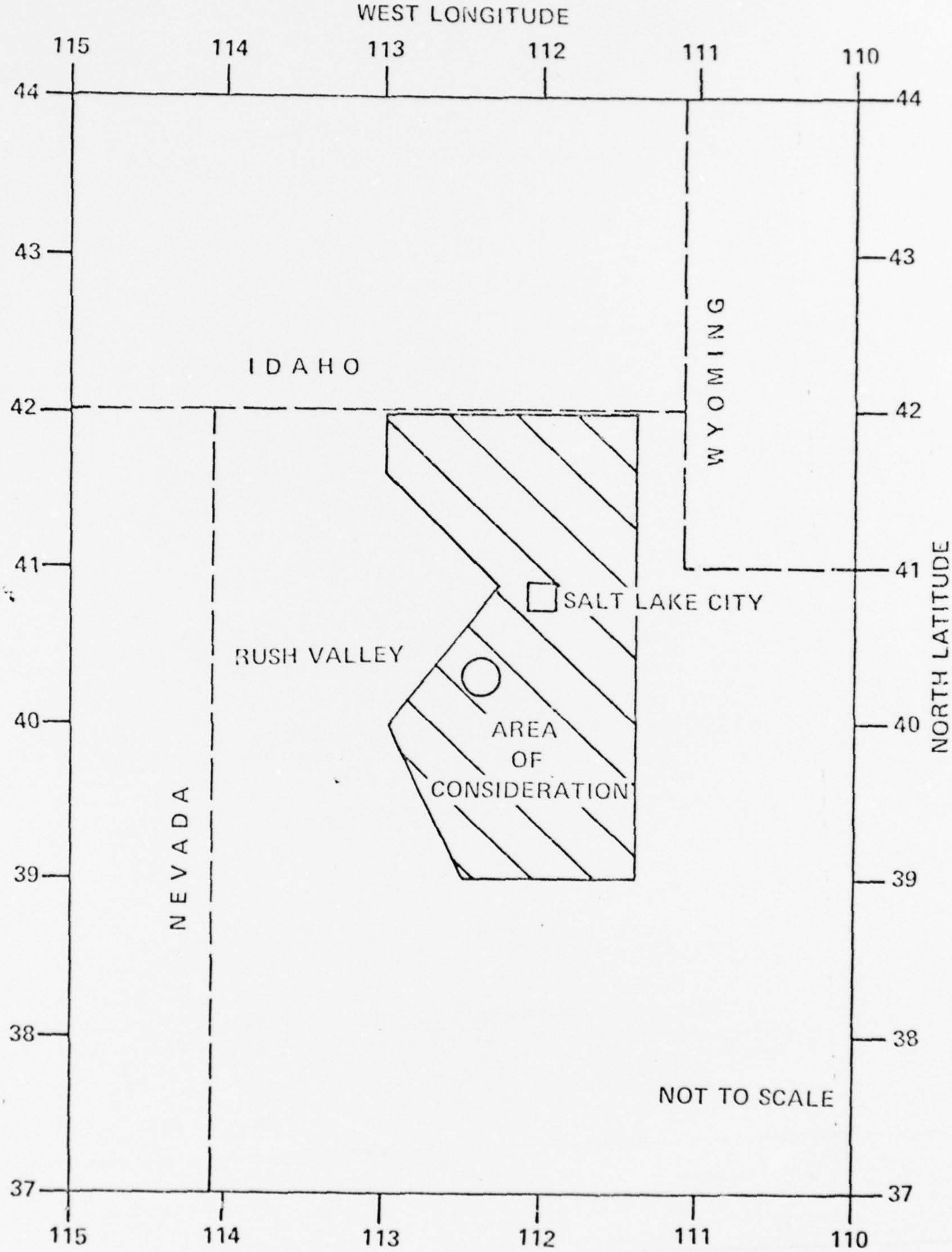
e. As another check on these analyses the data presented by Algermissen and Perkins, US Geological Survey Report,[7] 1976, for seismic source areas 33 and 34 was evaluated. The graphs constructed from these data yielded results consistent with the data presented here.

f. As a point of historical comparison, the average reoccurrence rate for intensity V events in Rush Valley is estimated to be once in 80 to 85 years. In one hundred and twenty-five years of recorded seismic history, of which seventy years has been judged to be complete, one intensity V event has been recorded in Rush Valley.[5] Thus, there is a good comparison between the actual historical data and the statistical evaluation presented above.

3. Analysis of Storage Structures and Weteye Bomb Characteristics.

a. While the risk of an intensity X earthquake is very small, an analysis of the Weteye bomb characteristics as well as the storage structures into which these Weteye bombs are to be placed is in order. This analysis will be focused on determining what might happen if an earthquake event of the maximum credible magnitude should occur. In this analysis we will look both at the effects due to ground motion as well as the effects on the bomb and the structure due to surface faulting. Before analyzing each of these stress conditions in detail, however, a review of Weteye bomb characteristics will be considered. This consideration will be presented first because it is applicable both to the ground motion as well as the surface faulting analysis.

b. The report[8] on testing of the Weteye bomb states that the bomb has been drop tested in its shipping and storage container from a height of 40 ft. Both side impact as well as end impact drop tests were conducted. The bomb itself outside of its shipping and storage container was subjected to a 10 ft. drop test. This drop test was conducted for side impact only. The result of these tests showed some damage to the bomb and to the bomb container both there was no leakage as a result of these tests. The



MAP OF AREA OF CONSIDERATION FOR SEISMIC EVENT STUDY NO. 2

FIGURE 5

<u>TABLE 2</u>

NUMBER OF EVENTS BY INTENSITY PER 10 YEARS
SEISMIC EVENT STUDY #2

Year Group \ Intensity	IV	V	VI	VII	VIII	IX
1853-60		2				
1861-70						
1871-80	5	1	1			
1881-90	1				1	
1891-1900	4	1		1		
1901-10		4		3		1
1911-20	3	6	2	1	1	
1921-30	2	1				
1931-40	5	1	1	1	1	
1941-50	8	5	3			
1951-60	12	8	1			
1961-70	19	10	4	2		
Events/Yrs	39/30	35/70	11/70	8/117	3/117	1/117
Decimal Equivalent	1.3	0.5	0.16	0.068	0.026	0.0085

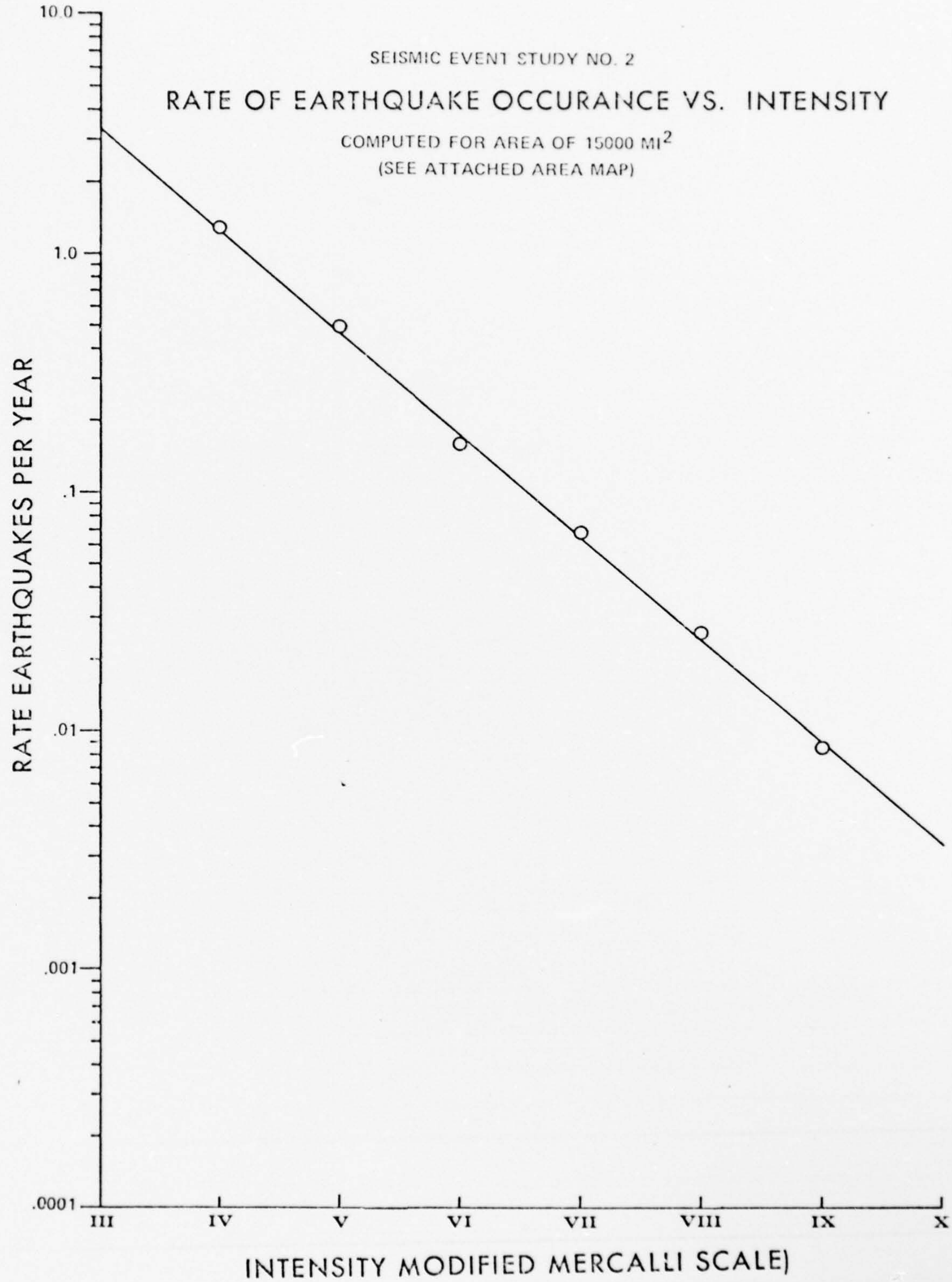
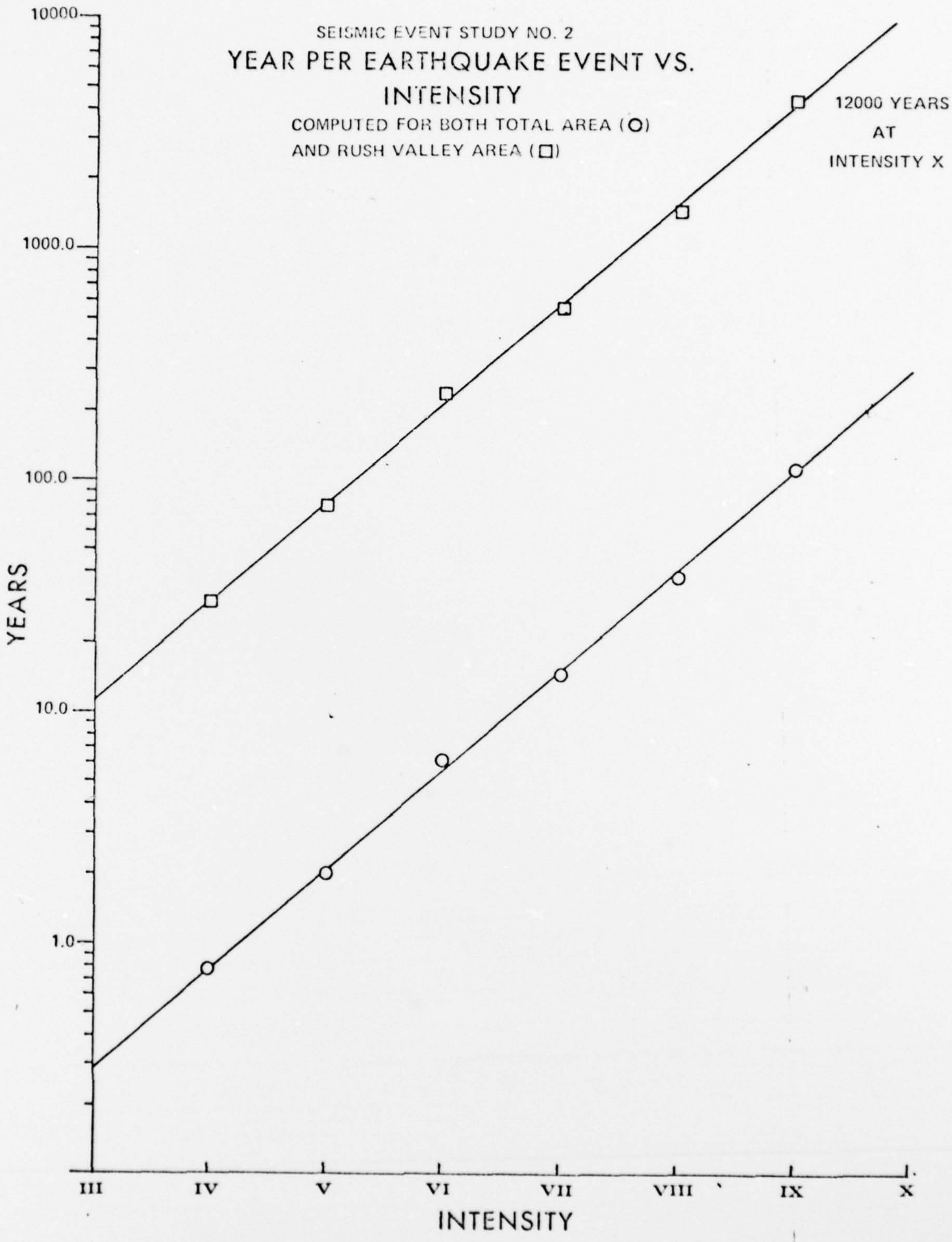

SEISMIC EVENT STUDY NO. 2
RATE OF EARTHQUAKE OCCURANCE VS. INTENSITY
COMPUTED FOR AREA OF 15000 MI2
(SEE ATTACHED AREA MAP)
RATE EARTHQUAKES PER YEAR
10.0
1.0
.1
.01
.001
.0001
III
IV
V
VI
VII
VIII
IX
X
INTENSITY MODIFIED MERCALLI SCALE)

FIGURE 6



SEISMIC EVENT STUDY NO. 2
YEAR PER EARTHQUAKE EVENT VS. INTENSITY
COMPUTED FOR BOTH TOTAL AREA (O)
AND RUSH VALLEY AREA (□)
12000 YEARS
AT
INTENSITY X
10000
1000.0
100.0
10.0
1.0
YEARS
III
IV
V
VI
VII
VIII
IX
X
INTENSITY

FIGURE 7

stress conditions caused by these drop tests are more severe than intensity X earthquake conditions. This conclusion is based upon an analysis of acceleration effects encountered in the drop tests. By making use of basic time and motion physics equations an estimate of acceleration effects developed during drop tests can be determined. The acutal calculation of these accelerations is shown at Inclosure 1 to this report. As can be seen the expected accelerations are in the range of 400g. When compared to the expected ground motion of 0.7g estimated for the maximum credible event earthquake, it can be seen that no credible damage can be considered.

c. An analysis of the storage structures at Tooele Army Depot South Area was conducted by Dr. Butler of the Corps of Engineers. Dr. Butler's evaluation is attached to this report as Inclosure 2. Basically, Dr. Butler's report states that these type storage igloos have withstood G-forces of magnitude 10 and greater. As previously stated, for the maximum credible earthquake in Utah, it is estimated that the acceleration values will be in the range of 0.7g. Further, it is estimated that the maximum acceleration developed by any earthquake would not exceed 2 to 3g. Therefore, it can be readily concluded that damage to these storage structures due to ground motion caused by an earthquake is not a credible possibility.

d. When considering if a fault line were to intersect a storage igloo, two points must be evaluated. First, what is the likelihood of occurrence of such an event, and second, what are the structural considerations for such an event. With respect to the first point, the likelihood of occurrence of a fault in Rush Valley can be estimated by considering the average reoccurrence interval for large earthquakes with respect to the identified fault scarps in the valley. There are five suspected fault scarps in Rush Valley and the average reoccurrence interval of the maximum credible earthquake (and associated faulting) is one in every 12,000 to 30,000 years. By dividing the maximum credible earthquake events between these five suspected scarp systems, the occurrence of faulting on the suspected scarp system north of the Tooele Army Depot South Area (the system of primary concern) can be considered to be one in 60,000 to 150,000 years. This represents the estimated occurrence of faulting on this particular scarp system north of the south depot area. The possibility of faulting actually extending through a storage structure is even less than the interval of suspected faulting. An estimate of the possibility of this occurrence escapes existing methods. Thus, it can be seen that the probabilities of a fault line actually carrying through a storage structure are extremely small. These conditions, however, were also analyzed in Dr. Butler's evaluation (Inclosure 2). Dr. Butler has stated that there are many forces interacting if such an event should occur and without extensive testing, the predicted response of the storage structure cannot be determined. Dr. Butler's evaluation does point out, however, that these structures could fail under such extreme stress conditions. In the event of a failure the concrete arch would crack and some blocks of concrete, along with a portion of the earth cover, might collapse onto the bombs stored within the structure.

e. Dr. Zaker, Department of Defense Explosives Safety Board, has performed an analysis[9] of probable damage to the bombs if the storage structure should fail. His analysis shows that some external damage to the shipping and storage container might occur, but the stresses involved are notably less than the stress conditions developed during the drop testing of the bomb. Dr. Zaker's evaluation shows that the maximum height from which the concrete rubble would fall would be 14 feet (the maximum height of the crown of the igloo arch). The drop test on the bombs were conducted from a height of 40 ft. The stress conditions of the drop test are notably in excess of the stress conditions resulting from the falling concrete blocks and earthen material, and therefore, it was concluded that rupture of the Weteye bombs due to structural collapse is not a credible possibility.

f. Dr. Zaker also discussed the affects of ground motion on the stacks of stored Weteye bombs within the structure. Dr. Zaker concluded that the worse possible condition would be for the bombs at the top of the stack to be thrown off resulting in impact on the floor of the structure. The maximum drop height of such an event would be approximately 48 inches. Again, the stresses imposed by this condition are less than the stresses imposed during the drop test. Therefore, it was again concluded that the leakage of Weteye bombs due to these stress conditions is not a credible possibility.

4. *Conclusions.*

The conclusions that can be arrived at, based upon both the seismic risk analysis as well as the structural analysis and the characteristics of the Weteye bombs, are as follows:

a. The reoccurrence interval for large seismic events in Rush Valley is very low, even though the reoccurrence intervals were estimated by conservative techniques.

b. Based on an analysis and testing of ammunition storage structures, the failure of these structures due to ground motion caused by earthquakes is not considered a credible possibility.

c. If a fault line should extend through a stroage structure due to a large seismic event, the structure may be damaged, but the handling and drop tests for the Weteye bombs show that they can withstand these stress conditions.

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DETERMINATION OF ACCELERATION
DEVELOPED BY
DROP TESTING OF WETEYE BOMBS

1. The time of the 40 ft. free fall is:

$D = \frac{1}{2} a t^2$

where,

D = Distance of fall

a = Acceleration of Gravity

t = Time of fall

$t = (2D/a)^{\frac{1}{2}}$

$t = 1.58$ sec

2. The average velocity (V) of the bomb during the free fall is:

$V = \frac{D}{t}$

$V = 25.32$ ft/sec.

3. Considering a one inch deflection (0.083 ft) as a result of impact, the time of acceleration (or deceleration) is:

$t = \frac{D}{V}$

$t = 3.28 \times 10^{-3}$ sec

4. The acceleration (or deceleration) developed by the impact is:

$$D = \tfrac{1}{2} a t^2$$

$$a = 2 \frac{D}{t^2}$$

$$a = 15{,}448 \text{ ft/sec}^2$$

or

<u>483g</u>

DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON, D.C. 20314

REPLY TO
ATTENTION OF:
DAEN-MCE

21 February 1978

Tooele Army Depot

Ammunition Storage Magazine, Arch-Type, Earth-Covered.
Seismic Resistance.

1. The following information on the seismic resistance capability of the storage magazines at Tooele Army Depot was a part of an overall DOD presentation made to Dr. Nielson, the Governor of Utah's Science Advisor, and his Seismic Hazard Advisory Council by a DOD group headed by Mr. T. Dashiell, ODDR&E (x-78714). The presentation was made in the Governor's office at an open meeting held on 17 February 1978. This data was prepared and provided by Dr. D. W. Butler, Office Chief of Engineers.

2. "The storage magazines at Tooele Depot are poured-in-place, reinforced concrete, semi-circular arch-type, and are commonly called igloos. These magazines were constructed in WWII. There are two different igloos. Both have the same floor width of 26 feet and structural cross-section. One is 60 feet in length, and the other is 80 feet in length inside. The steel reinforced concrete semi-circular arch has an inside radius of 13 feet, with an arch section thickness at the haunch of 16 inches and of 6 inches at the crown. The haunch is dowelled to a continuous steel reinforced concrete wall foundation which is integral with the steel reinforced concrete floor slab. There are 12-inch thick steel reinforced concrete end walls, with the front wall integral with a wing-wall and reinforced to 18-inch thickness around the door entrance. These igloos were constructed at natural grade and mounded over with earth cover, to a depth of two feet at the crown and sloped to natural grade around the sides and rear of the igloos.

3. "These igloos were designed primarily for the protection of stored munitions from the maximum air blast waves, ground shock waves and fragment penetrations possible if the contents of an adjacent magazine were to explode, for whatever reason. In the designs, the structural requirements for resistance to earthquake ground motions were considered. However, these resistance requirements are much less than the resistance requirements to resist the effects of an explosion of the munitions in an adjacent magazine. The two events, the explosion of an adjacent magazine of munitions and a large near earthquake, have both

Incl 2

similar and differing energy radiation mechanisms and magazine structural loading mechanisms; but the same magazine structural resistance mechanisms and resistance capacity are effective for both events.

4. "A munition explosion in an adjacent magazine creates an air blast wave that diffuses from the magazine site at a minimum velocity of the speed of sound in air. It also creates ground shock waves that diffuse from the explosion as dilatational type waves at a velocity commensurate with the elastic properties of the ground medium. In normal alluvial type soil structures, this velocity would approximate 2,000 feet per second. A near large magnitude earthquake of shallow depth focus would create primary elastic waves o f the P-type (dilatational) and S-type (distortional). Surface waves of the Rayleigh and Love type would also be expected.

5. "Igloos of this design were subjected to a series of 8 tests in 1945 at the Naval Proving Ground at Arco, Idaho. In this test series, donor magazines (as they are called) filled with up to 150 tons of high explosives (Torpex and Amato) were exploded and the effects were observed and measured on test magazines (acceptor magazines as they are called), also fully loaded with munitions. The test (acceptor) magazines were placed at various distances and configurations relative to the donor magazines. The U.S. Coast and Geodetic Survey, Dr. D. S. Carder supervising, provided instrumentation, control and seismological results from these tests.

6. "The maximum loadings on these acceptor magazines from these tests were:

- 11.3 g's horizontal acceleration, or 11.3 times the acceleration of gravity horizontal accelerations, at the floor level of the magazine.

- 43 psi ground level blast pressure. The lowest possible pressure loading on the shell would be 21.5 psi. For the worst case of shell deflection, this load is applied on one-half of the magazine arch section.

7. "Tests conducted in 1964 at the Naval Test Station, China Lake, California, and in the ESKIMO test series commenced in 1971 at the same test station, with improved instrumentation indicates that the maximum ground acceleration and pressure parametric values obtained in 1945 were low for equivalent explosive yields and distances. Additionally, vertical accelerations up to 16.0 g's were recorded in the later tests, where no instrumentation for this effect was installed in the 1945 test series.

8. "The damages suffered to the Tooele type magazines in the Arco tests were negligible. Some minor cracking in the arch section walls occurred, and some concrete spalling occurred in the front wall door supports from direct head-on air blast pressure. No explosions occurred of any munitions stored in the acceptor magazines.

9. "A large earthquake event would subject the Tooele magazines to a regime of ground motion for up to 30 seconds, with wave period groups ranging up to 2.0 seconds, depending on the distance from the fault zone on which the earthquake occurred. Assume the Maximum Credible Earthquake occurred which could be possible geologically in the region affecting the Tooele Depot. Also, assume it could have maximum acceleration components of 1.0g horizontal and 0.5 vertical at the Depot site.

10. "A static load analysis of the arch section in the transverse direction, considering the ends of the arch shell open without the 1-foot-thick end walls, at the elastic limit of the arch for lateral loading (deflection), gives a load capacity equal to 3.5 g's of acceleration (24 kips). Considering the actual increased transverse strengthening of the shell section by the 1-foot-thick end walls, and the membrane strength effect, the calculated load capacity would be doubled to 7.0 g's, as a conservative estimate for the 80-foot length magazine. The 60-foot magazine would be stronger in the transverse direction. Both magazines are stronger in the longitudinal direction than in the transverse direction.

11. "These conclusions can be correlated to the actual transverse air blast loading at the Arco tests. The 21.5 psi pressure loading on the shell, considering the worst case loading when the blast front reaches the crown of the arch producing an asymmetrical loading, is equivalent to 63 kips per lineal foot of length (The buckling load of the arch section in compression is larger than this value). This is equivalent to a 9.2 g loading. The igloo sustained only minor damage to this loading as noted.

12. "The resistance capacity of these igloos to earthquake ground motion certainly is very large. They are very stiff structures and can be expected to move very closely with the ground motion. The lowest horizontal fundamental mode of vibration has a period of about 0.06 seconds transversely with about 0.04 second longitudinally. The 80-foot magazine has a higher period transversely and a lower period longitudinally than the 60-foot magazine. As the predominant periods of expected earthquake ground motion would most likely be higher than these values, no dynamic response amplification should be expected.

13. "Should site ground fissuring or faulting occur, and it trended directly under a magazine, there are a number of distinct possibilities which could occur based upon observations of such occurrences to building structures in other earthquakes. The ground could fissure under a magazine with essentially no effect on the magazine, as the magazine is built essentially upon the natural ground and is very strong acting as a beam structure. The ground could fissure around the magazine, as has been observed in many instances to stiff building basement structures. The ground fissure could also rupture the magazine:

14. "If a magazine ruptures, blocks of the concrete shell could fall as far as 10-13 feet onto the stored containers. The potential for damage to the stored products in this instance, and in the instances when the acceleration of the structure could topple the stored containers, are not considered critical. Dr. Zaker will discuss this area."

References:

a. Technical Paper No. 3, Army-Navy Explosives Safety Board, "Igloo Tests," 1945 (Revised 6 November 1947), Naval Proving Ground, Arco, Idaho.

b. U.S. Naval Ordnance Test Station, China Lake, CA, "Report of 100,000 Pound Igloo Test (U)," R. H. Miller and R. E. Boyer, 22 January 1964.

c. DOD Explosives Safety Board, "ESKIMO I, II and IV, Magazine Separation Tests," 26 February 1973, September 1974, and March 1977, respectively, Naval Weapons Center, China Lake, California.

RICHTER MAGNITUDES AND MERCALLI INTENSITIES

1. A selected scheme of measuring earthquake magnitudes was originally developed and used by Prof. C. F. Richter of the California Institute of Technology. This method has been adopted for use by Seismologists. The Richter Magnitude is an index number characteristic of the size of an earthquake and independent of the location of the recording station. The earthquake magnitude is based on the maximum trace amplitude measured by a standard type seismograph at a given distance from a seismic event. For example, an earthquake of Richter magnitude 3 would register a maximum trace amplitude of 1 mm on a Wood-Anderson standard torsion horizontal seismograph located a distance of 100 km from the earthquake epicenter. For this same instrument located the same distance from the epicenter, earthquakes of Richter magnitude 4 and 5 would give maximum deflections of 10 and 100 mm, respectively. As can be seen, the Richter scale is logarithmic, that is, an earthquake of magnitude 5 causes 10 times more deflection than a magnitude 4 earthquake, and 100 times more deflection than a magnitude 3. Thus, it can be seen that as the Richter magnitude value increases one index number, the power of an associated earthquake increases in a logarithmic fashion.

2. In the epicentral area, earthquakes of Richter magnitude 2.5 to 3.0 are commonly felt; magnitudes of 4.5 to 5.0 commonly cause minor damage; magnitudes of 6.0 may cause breaking at the ground surface and cause widespread damage in populated areas; and earthquakes of magnitude 7.0 to 8.0 cause severe damage in populated areas. For comparison purposes, the magnitude of the 1964 Alaskan earthquake was magnitude 8.4; the San Fernando Valley earthquake of 1971 was magnitude 6.6; and the 1952 Magna, Utah earthquake was magnitude 5.0.

3. The Modified Mercalli Intensity Scale is used to give an index of the effects of shaking, and the possible damage, resulting from an earthquake. This intensity scale may be applied at the epicentral area as well as at distances away from the epicentral area. The intensity rating is generally highest at the epicenter (maximum intensity) and decreases radially outward. The descriptions of effects for various Mercalli intensities as modified by C. F. Richter is shown on the following pages.

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Intensity (Modified Mercalli Scale)	Description
I	Not felt. Marginal and long-period effects of large earthquakes.
II	Felt by persons at rest, on upper floors, or favorably placed.
III	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt. Standing cars rock. Windows, dishes, doors rattle. Glasses clink. In the upper range of IV wooden walls and frame creak.
V	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knicknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school).
VII	Difficult to stand. Noticed by drivers of cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Falling of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII	Steering of cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Falling of stucco and some masonry walls. Twisting, falling of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

Intensity (Modified Mercalli Scale)	Description
IX	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake foundations, sand craters.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	Rails bent greatly. Underground pipelines completely out of service.
XII	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

SOURCE: C. F. Richter, "Elementary Seismology," W. H. Freeman & Co. Inc., San Francisco, 1958, pp. 137-138.